GET-6497A

Generating Station Protection

INTRODUCTION

This guide is concerned primarily with short circuit protection and protection for abnormal operating conditions for generating stations. It specifies the minimum recommended protection for steam turbine generators, for hydro generators, and for gas turbine generators. Additional desired protection should be provided if it is economically justified. Unless otherwise stated, these recommendations apply to either attended or unattended stations having generators rated as follows:

- 1000 kva and higher, any voltage
- 5 kv and higher, any kva
- 2.2 kv and higher, and 501 kva and higher

The guide contains the following sections:

- Recommended Generating Station Protection – presents recommended and optional protection for specific generator applications and arrangements.
  - Unit generator-transformer installation
  - Generators bussed at generator voltage
- Excitation System Protection – presents recommended and optional protection for available excitation systems.
  - Alterrex
  - Generrex
- Considerations Involving Individual Forms of Relaying – considers special problem areas, setting information and application rules not provided elsewhere, or any other special considerations pertinent to a particular type of relay or protection.
  - Stator short-circuit protection
  - Loss-of-excitation protection
  - Reverse power (anti-motoring) protection
  - Unbalanced current (single phasing) protection
  - Tripping modes
  - Generator back up protection
  - Protection for accidentally energizing a generator on turning gear
  - Protection during start-up or shutdown
  - Current transformers
  - Potential transformers
  - Sub-synchronous resonance
- Other Protective Considerations – considers supplementary protection and other forms of protection not covered earlier.

REFERENCES

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UNIT GENERATOR-TRANSFORMER INSTALLATION

Figure 1 shows a typical unit generator-transformer installation with high impedance grounding through a distribution transformer. In this arrangement, the grounding impedance is usually selected to limit the current for a single line-to-ground fault at the terminals of the generator to 10 primary amperes or less. Figure 1 shows graphically the various available forms of protection, while relay recommendations are given in Table 1 where device numbers correspond to the encircled numbers in Fig. 1.

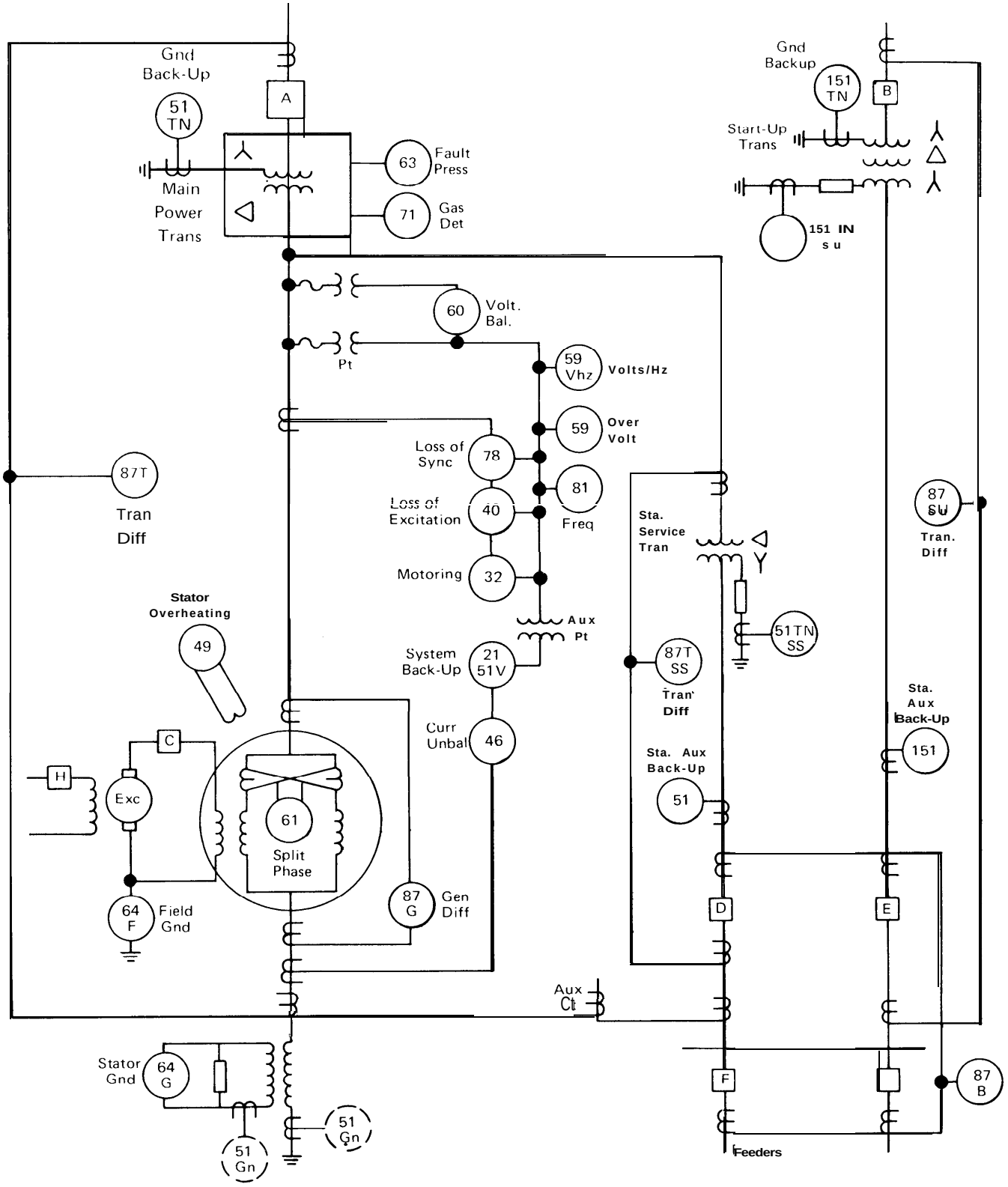


Figure 1. Unit generator transformer arrangement.

TABLE 1

Device	Quantity and Type	Function, Relay Control led or Breakers Tripped	Device	Quantity and Type	Function, Relay Controlled or Breakers Tripped
21	3-CEB5lB (a) (w) 1-CEBl3C (a) (w)	21x	78	1 -GSY51 A (p) and 1-CEX57E (p)	94G2
21x	1-SAM14	86G	81	1-SFF21A (q)	94G2
32	1 -GGP53C (b)	94G 1	86B	1-HEA61	D,E,F,G
40	1-CEH51A (c) 1 -CEH52A (c)	94G 1	86G	1 -HEA61	A,C,D,H, shutdown (BFI)*
46	1 -SGC12A (d)	94G 1	86T/SU	1 -H EA61	B,E
49	1-IRT51A (e)	Alarm (f)	87B	3-PVD11 C or 3-PVD21 (r)	86B
51	3-IAC53A (g) or 3-I FC53A	86G	87G	3-CFD22 (s)	86G, 87X
51 /GN	1-IAC53A (g) (y) or 1-IFC53A	86G	87T	3-BDD 15B (t) or 3-STD15C (t)	86G
51 /TN	1-IAC53A (g) (w) or 1 -I FC53A	86G	87T/SS	3-STD 15C or 3-STD 15C	86G
51TN/SS	1-IAC53A (g) or 1-IFC53A (g)	86G	87T/SU	3-BDD1 5B or 3-STD 15C	86T/SU
51v	3-IJCV51A (h) (w) or 3-IGCV51A (h) (w)	86G	87X	1-HGA14A	CO_2 (z)
59	1-IAV71B (i)	94G 1	94G 1	1 or 2-HFA53K	A,C,H (x) (BFI)*
59V/HZ	2-STV11A (j)	94G 1	9462	2 or 2-HFA53K	A (BFI)*
60	1-CFVB11B (k)	Alarm	151	3-IAC53A (g) or 3-IFC53A	86T/SU
61	3-IAC53B (ℓ) or 3-IFC53B (ℓ)	86G, 87X	151TN	1 -IAC53A (g) or 1-IFC53A	86T/SU
63	l-Type 900-1A (m)	86G	151 TN/SU	1-IAC53A (g) or 1-IFC53A (g)	86T/SU
64F	1-PJG12 (n)	86G			
64G	1 -IAV51 K	86G, 87X	AUX CT	3-JARO (u)	
71	1 -Gas Detector (0)	Alarm	AUX PT	3-JE27 (v)	

***(BFI) = Breaker failure initiate**

(a) The CEB13C has three units in one case and may be used in place of 3-CEB51B. The CEB51B or CEB13C is used where lines are protected with distance relays.

(b) For internal combustion engines or gas turbine generators, substitute 1-ICW51A.

(c) The CEH51 has a single mho function which operates with no external time delay. The CEH52 has two independent mho functions and a built-in timer which operates in conjunction with one of the mho units. If time delay is desired with the CEH51, use 1-SAM11A. For attended or for unattended generators smaller than 7500 kVA, may substitute 1-IC-2820-A100 for connection in field circuit.

(d) Substitute SGC12B if a relay with I_2 meter is desired. For generators smaller than 150 MVA, may substitute INC77B.

(e) For unattended generators or generators rated 7500 kVA or higher. If generator has no RTDs, substitute 1-THC11A. This protection is not used on conductor cooled machines.

(f) For unattended generators initiate automatic runback and shutdown.

(g) Substitute IAC51A or IFC51A if inverse time characteristics are desired.

(h) The IJCV is a voltage restrained overcurrent relay. The IGCV is a voltage controlled overcurrent relay. Either relay is used where line protection is overcurrent relaying.

(i) For hydro or gas turbine generators only.

(j) Two STV relays normally supplied on LSTG and MSTG generators. Supplied as an optional item on gas turbines. One or more relays should be used with all types of generators for transformer protection.

(k) Used to open trip circuits of devices 21, 32, 40, 51V, 78. Can also be used to remove regulator from service.

(ℓ) For multi-circuit hydro generators.

(m) Type 900-1A fault pressure relay.

(n) The PJG12 can be set with zero or 2 seconds time delay. In general, it is recommended that time delay be used with this protection.

(0) Gas Detector Relay. Only applicable on conservator or atmo-seal type of transformers.

(P) Optional. Used when during loss of synchronism, the electrical center is in either the step up transformer or in the generator.

(q) Underfrequency protection for the turbine. One or more relays may be required to provide protection. See reference 6.

(r) The PVD21 is faster version of the PVD1 1.

(s) For generators smaller than 2000 kVA, the IJD52 may be substituted. The IJD52 is also used on class 1 E standby generators.

(t) If HV bus arrangement is such that two HV breakers are Involved, use 3-BDD16B or 3STD16C.

(u) Use with 87T.

(v) Use with 21 and 51V.

(w) For two step tripping with external fault backup relays, devices 51TN, 51V or 21X would first trip breaker A and then after a short time delay, control device 86G. This would require an additional RPM1 IA or SAM11A timer to be controlled by 51TN and 51V.

(x) A generator may have a main field breaker (C) or an exciter field breaker (H) or a generator may have both. If both field breakers are used, both should be tripped by 94G1 and 86G.

(y) 51GN is backup for stator ground faults. Two possible locations for this protection are shown.

(z) Used only on enclosed air cooled machines.

GENERATORS BUSSED AT GENERATOR VOLTAGE

Figure 2 shows a typical installation where generators are bussed at generator voltage. In this arrangement, the generator is generally low resistante grounded. The grounding resistance is usually selected to limit the generator's contribution to a single line-to-ground fault at its terminals to less than rated full load current. Figure 2 shows graphically the available forms of protection, and relay recommendations are given in Table 2, where the device numbers correspond to the encircled numbers in Fig. 2.

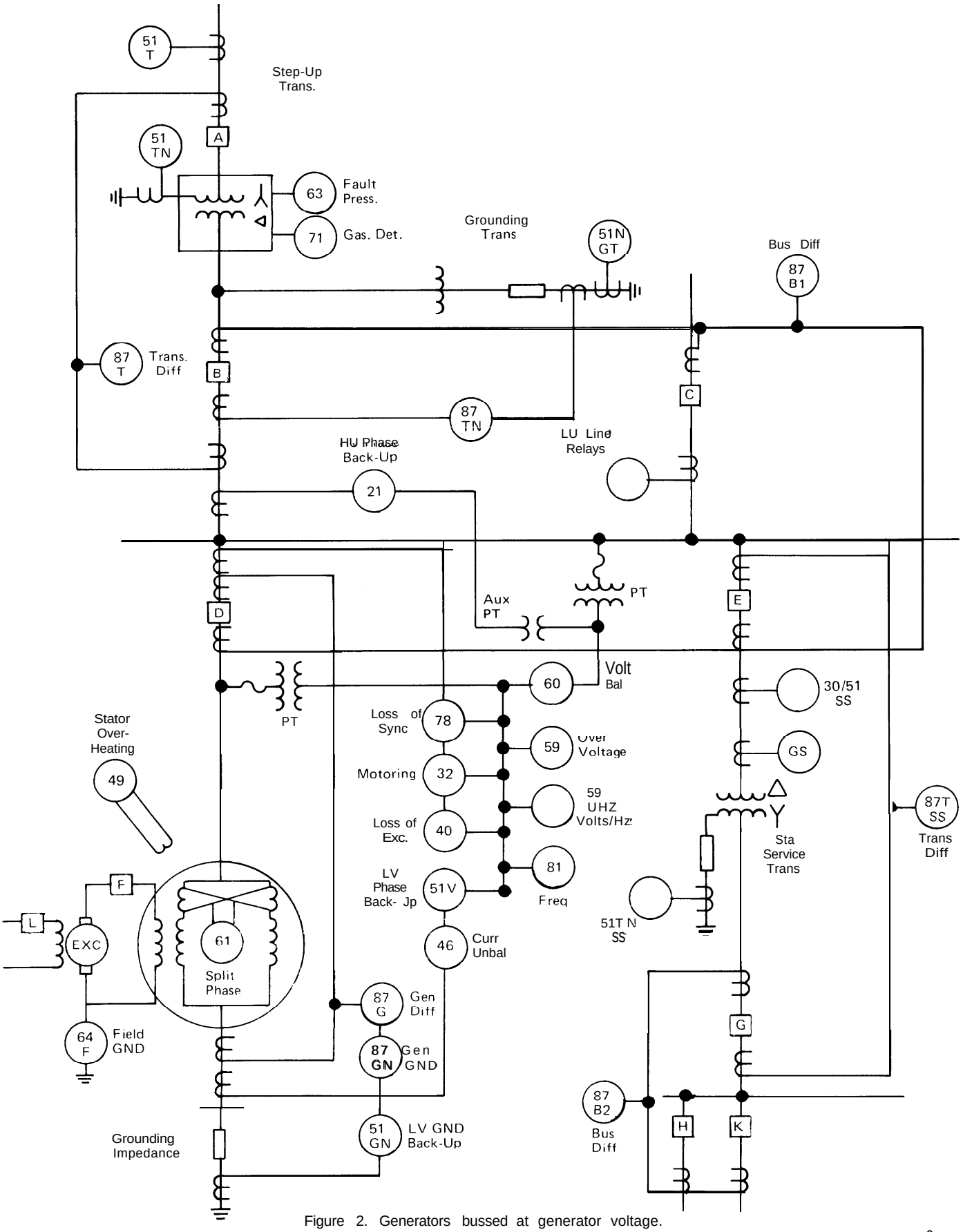


Figure 2. Generators bussed at generator voltage.

TABLE 2

Device	Quantity and Type	Function, Relay Controlled or Breakers Tripped	Device	Quantity and Type	Function, Relay Controlled or Breakers Tripped
21	3CEB51 B (a)	21X	64F	1 -PJG 12 (n)	86G
	1-CEB13C (a)		71	1-Gas Detector (o)	Alarm
21x	1-SAM11A	B	78	1-GSY51A (p)	94G2
32	1 -GGP53C (b)	94G1		and 1-CEX57E (p)	
40	1 -CEH51 A (c)	94G1	81	1-SFF21A (q)	94G2
	1 -CEH52A (c)		86B1	1-HEA61	B,C,D,E. (BFI)*
46	1 SGC12A (d)	94G1	86B2	1-HEA61	G,H,K
49	1-IRT51A (e)	Alarm (f)	86G	1 -HEA61	D, L,F, shutdown
50/5 1 SS	3-IAC53B (g)	E			(BFI)*
	or 3-IFC53B (g)		86T	1 -HEA61	A,B
51GN	1-IAC53A (g) (w)	86G	86T/SS	1 -HEA61	E,G
	or 1-IFC53A (g)		87BI	3-PVD11C	86B 1
51 N/GT	1-IAC53A (g)	86T		o r 3-PVD21 (r)	
	or 1-IFC53A (g)		87B2	3-PVD1 1C	86B2
51T	3-IAC53A (g)	86T		or 3-PVD21 (r)	
	or 3-IFC53A (g)		87G	3-CFD22 (s)	86G, 87X
51TN	1-IAC53A (g)	86T	87GN	1-ICC52A (t)	86G, 87X
	or 1-IFC53A (g)			or 1-IFC53A (t)	
51TN/SS	1-IAC53A (g)	86T/SS	87T	3-BDD15B (u)	86T
	or 1-IFC53A (g)			or 3STD15C (u)	
51V	3-IJCV51A (h) (w)	86G	87TN	1-ICC52A	86T
	or 3-IGCV51A (h) (w)			1-IFC53A	
59	1 -IAV71 B (i)	94G 1	87T/SS	3-BDD15B	86T/SS
59VHZ	2-STV11A (j)	94G 1		or 3-STD 15C	
60	1 -CFVB11B (k)	Alarm	87X	1-HGA14A	CO_2 (y)
61	3-IAC53B (ℓ)	86G, 87X	94G 1	1 or 2-HFA53K	D,F,L (x) (BFI)*
	or 3-IFC53B (ℓ)		94G2	1 or 2-HFA53K	A, (BFI)*
63	I-Type 900-IA (m)	86T	AUX PT	3-JE27 (v)	
			GS	Ground Sensor (z)	86T/SS

***(BFI) Breaker Failure Initiate**

(a) The CEB13C has three units in one case and may be used in place of 3-CEB51B. The CEB51B or CEB13C is used where lines are protected with distance relays. May substitute 3-IBCV53.

(b) For internal combustion engines or gas turbine generators, substitute 1-ICW51A.

(c) The CEH51 has a single mho function which operates with no external time delay. The CEH52 has two independent mho functions and a built-in timer which operates in conjunction with one of the mho units. If time delay is desired with the CEH51 use 1-SAM11A. For attended or for unattended generators smaller than 7500 kVA, may substitute 1-IC-2820-A100 for connection in field circuit.

(d) Substitute SGC12B if a relay with an I_2 meter is desired. For generators smaller than 150 MVA, may substitute INC77B.

(e) For unattended generators or generators rated 7500 kVA or higher. If generator has no RTDs, substitute 1-THC11A. This protection is not used on conductor cooled machines.

(f) For unattended generators initiate automatic runback and shutdown.

(9) Substitute IAC51A or IFC51A if inverse time characteristics are desired.

(h) The IJCV is a voltage restrained overcurrent relay. The IGCV is a voltage controlled overcurrent relay. Either relay is used where line protection is overcurrent relaying.

(i) For hydro or gas turbine generators only.

(j) Two STV relays normally supplied on LSTG and MSTG generators. Supplied as an optional item on gas turbines. One or more relays should be used with all types of generators for transformer protection.

(k) Used to open trip circuits of devices 32, 40, 51V, 78. Can also be used to remove regulator from service.

(ℓ) For multi-circuit hydro generators.

(m) Type 900-1A fault pressure relay.

(n) The PJG12 can be set with zero or 2 seconds time delay. In general, it is recommended that time delay be used with this protection.

(o) Gas Detector Relay. Only applicable on conservator or atmo-seal type of transformers.

(P) Optional. Used when during loss of synchronism, the electrical center is in either the step up transformer or in the generator.

(q) Underfrequency protection for the turbine. One or more relays may be required to provide protection. See reference 6.

(r) The PVD21 is faster version of the PVD11.

(s) For generators smaller than 2000 kVA, the IJD52 may be substituted. The IJD52 is also used on class 1E standby generators.

(t) Use if generator's contribution to a ground fault at its terminals is limited to less than generator rated full load current.

(U) If HV bus arrangement is such that two HV breakers are involved, use 3-BDD16B or 3-STD16C.

(v) Use with 21.

(w) For two step tripping with external fault backup relays, devices 51V and 51GN would first trip breaker D and then after a short additional time delay, control device 86G. This would require an additional RPM11A or SAM11A timer to be controlled by 51GN and 51V.

(x) A generator may have a main field breaker (F) or an exciter field breaker (L) or a generator may have both. If both field breakers are used, both should be tripped by 94G1 and 86G.

(y) Used only on enclosed air cooled machines.

(z) A ground sensor is usually supplied in metal clad switchgear or on cable circuits. It consists of window CT plus either a PJC11 or a HFC11 instantaneous overcurrent relay.

EXCITATION SYSTEM PROTECTION

ALTERRAEX EXCITATION SYSTEM

Figure 3 shows the ALTERREX excitation system as used on large steam turbine generators. It should be noted that a number of generator protective functions are incorporated as standard features of the excitation equipment. Many specialized protective functions are incorporated as required for protection of the specific excitation system components unique to this particular design. Figure 3 shows schematically the various forms of protection, while the device designations are given in Table 3.

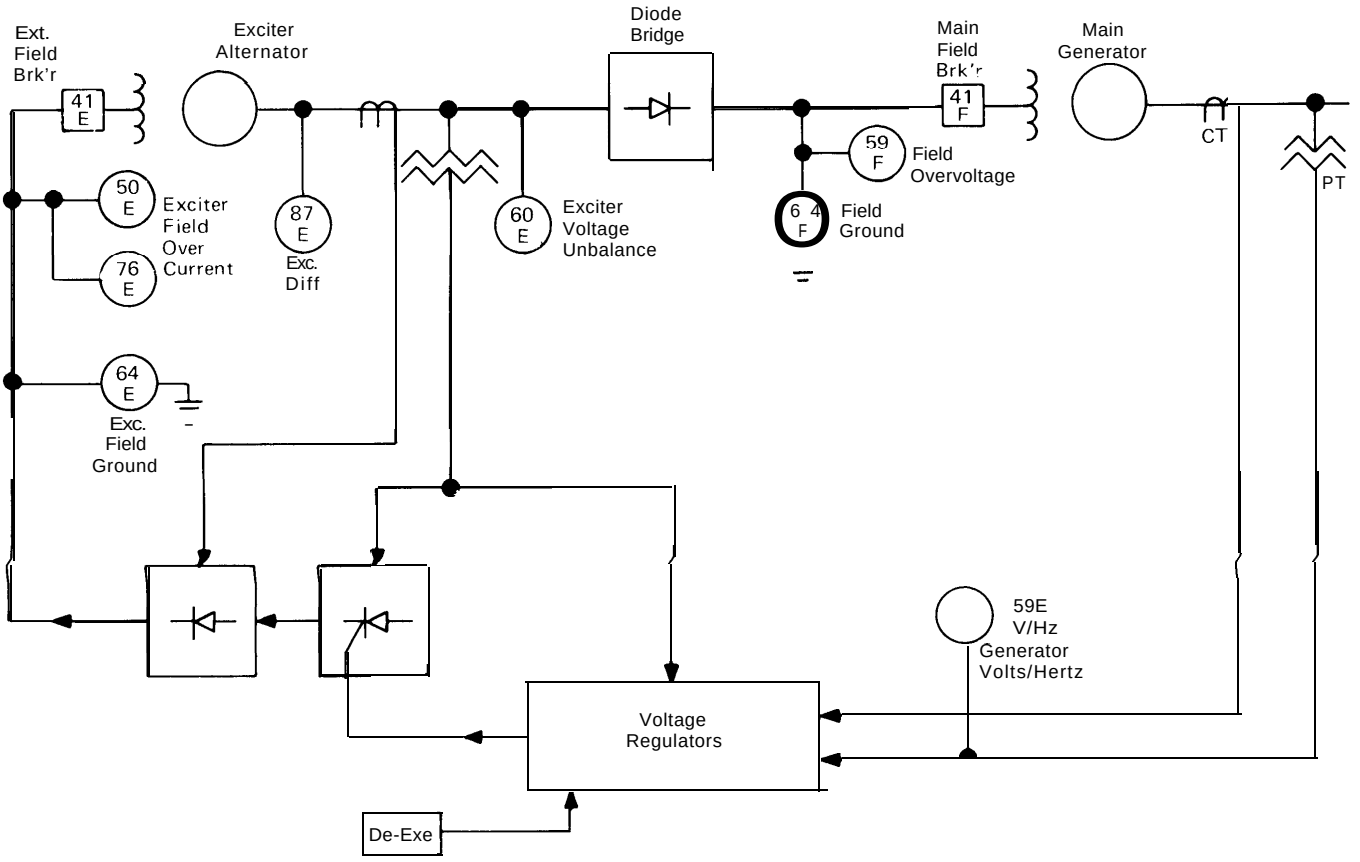


Figure 3. Alterrex excitation system protective equipment.

TABLE 3
ALTERREX EXCITATION SYSTEM

Device Function	Device Description	Device Identification	Function, Relay Controlled or Breakers Tripped
59F	Field Overvoltage	JA114*	86Gt
50E/76E	Exciter Field Overcurrent Instantaneous/ Inverse Time	*	83Rt
59E V/HZ	Generator Volts Per Hertz	MA336*	94G-1 t
60E	Exciter Voltage Balance	MA305**	86Gt
64E	Exciter Field Ground	YA122*	Alarm
64F	Generator Field Ground	YA122*	86Gt
87E	Exciter Differential	3-CFD 22""	86G-t
83R	Regulator Tripping Relay	AC to DC	Control Mode

Notes:

* **This** equipment supplied as an integral part of excitation equipment.

** **These protective functions are optional. The 60E provides more complete** protection **than 87E which covers only the** exciter **alternator.**

† **All excitation systems will be equipped** with **two independent, redundant shutdown methods:**

- **Main field breaker or equivalent. (41 F)**
- **Exciter field breaker or equivalent. (41 E)**
- **De-excitation** thru **control action of voltage regulators.** (DE-EXC)

GENERREX EXCITATION SYSTEM

Figure 4 shows the GENERREX excitation system as used on large steam turbine generators. It should be noted that a number of generator protective functions are incorporated as standard features of the excitation equipment. Many specialized protective functions are incorporated as required for protection of the specific excitation system components unique to this particular design. Figure 4 shows schematically the various forms of protection, while the device designations are given in Table 4.

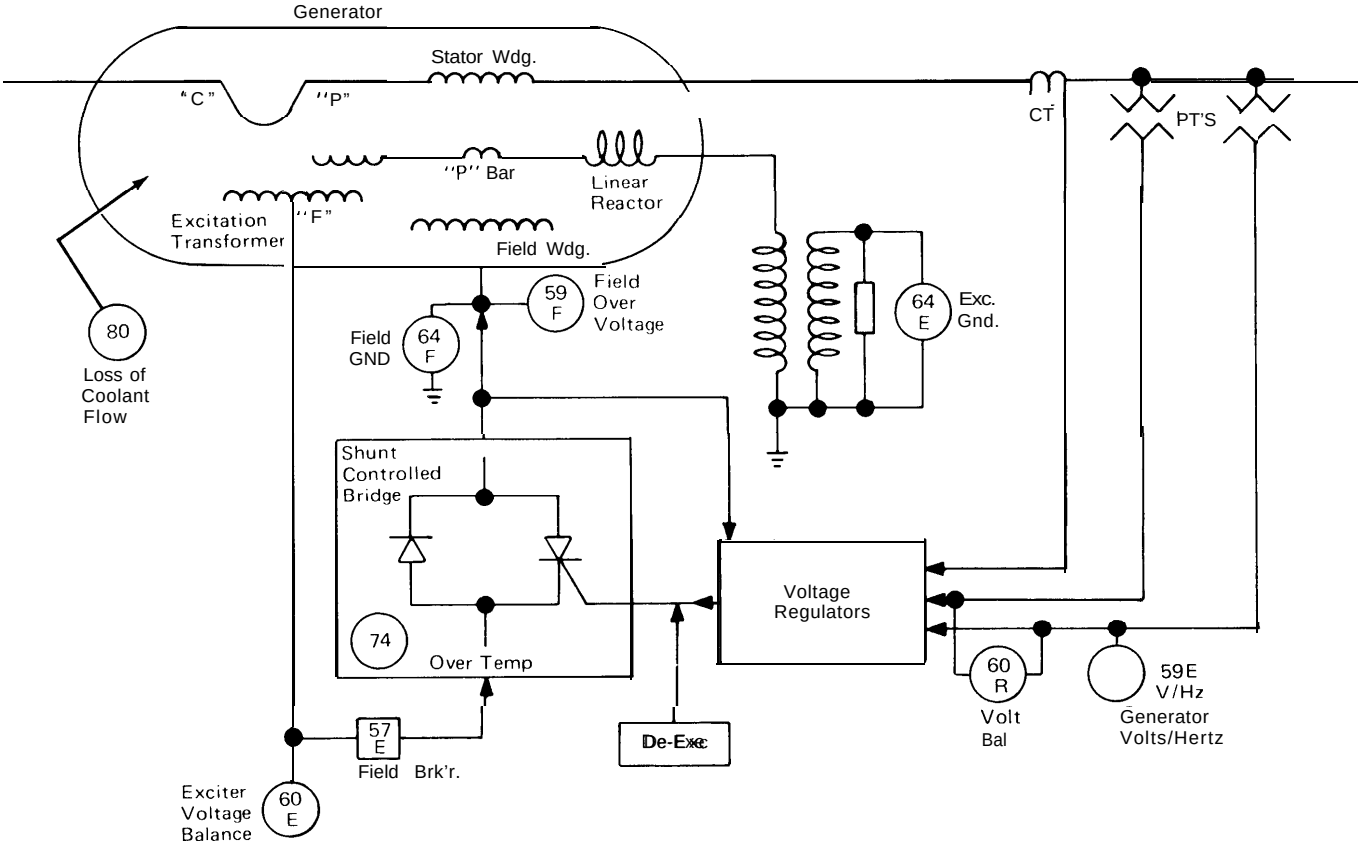


Figure 4. Generrex excitation system protective equipment.

TABLE 4
GENERREX EXCITATION SYSTEM

Device Function	Device Description	Device Identification	Function, Relay Controlled or Breakers Tripped
59F	Field Overvoltage	*	86G †
59E V/HZ	Generator Volts Per Hertz	*	94G-1 †
60E	Exciter Voltage Unbalance	*	86G †
60R	Voltage Balance	*	Alarm
64E	Exciter Winding Ground	IAV 51K**	86G †
64F	Generator Field Ground	YA1 22"	86G †
74	Rectifier Over Temperature	*	Alarm
80	Generator/Exciter Winding Loss of Coolant Flow	*	Turbine Runback Then 86Gt

Notes:

* This equipment supplied as an integral part of the excitation equipment as printed circuit boards.

** These relays supplied as standard feature of the excitation systern.

† All excitation systems will be supplied with two independent, redundant shutdown methods:

- Main field breaker or equivalent. (41 F)
- Exciter shorting breaker. (52E)
- De-excitation thru control action of voltage regulators. (DE-EXC)

INDIVIDUAL FORMS OF RELAYING

The primary purpose of this section is to present special considerations involving individual forms of relaying. Items under this heading are intended to indicate special problem areas, application rules not provided elsewhere, changes in application rules, or any other special considerations pertinent to a particular type of relay or protection.

STATOR SHORT-CIRCUIT PROTECTION

Differential Protection (Type CFD22B)

The only problem which may require consideration with this type of protection is the possibility of high voltages in the CT circuits during internal faults, and therefore the need for Thyrite limiters across each phase of the CT secondaries. It shou Id be noted that this problem is of primary concern when a group of generators are bussed at generator voltage and there are no external impedances to limit the current flow into a fault within a differential zone. This is not generally a problem with the unit generator-transformer arrangement since transformer impedance will limit fault current.

Current transformer secondary voltages are a function of secondary fault current, impedance of the differential operate circuit, and CT tap being used. Since a rigorous calculation of this voltage is complex, two simple rules have been evolved to determine the need for Thyrite limiters. These rules are:

- When the full CT winding is being used, limiters are not required when the secondary currents are below 84 amperes.

- When a lower tap is used on the CT, limiters are not required when the current is less than 84 x (active turns/total turns)2.

It should be noted that when an IJD differential relay is used, the limiting current is 50 amperes.

Ground Fault Protection (Type IAV51K)

There are several points which might be of interest with this protection.

- The recommended setting for this relay is 5.4 volts pickup, No. 10 time dial. With this setting, about 96 percent of the generator winding will be protected for ground faults.

- When grounded wye-grounded wye PTS are used on the generator terminals, the IAV51K will not always coordinate with the PT fuses for ground faults on the PT secondaries. Since the IAV provides better thermal protection than the fuses, some utilities accept this shortcoming and continue to use the recommended settings. The No. 10 time-dial setting provides maximum obtainable coordination with the low side PT fuses.

  Where this situation is not acceptable, utilities will unground the PT secondary neutral and ground any one of the secondary phase wires. With this approach, a ground fault on one of the other phase wires would create a phase-to-phase fault which would be cleared by the fuses and which would not affect the IAV51K.

- A problem not often recognized by users is the possibility of incorrect operation of the IAV for ground faults on the high-voltage side of the unit transformer. When a high-tension ground fault occurs, a voltage may appear at the generator neutral due to the capacitance coupling between transformer windings. The magnitude of this voltage, on the distribution transformer secondary basis, can be as high as 20 volts which is well above the sensitive pick-up setting (5.4 volts) of the IAV. The No. 10 time dial setting generally used provides more than enough time to ride over the clearing of system ground faults and thereby prevents undesired IAV operation.

- Where PT secondary neutrals are not grounded and coordination with PT fuses is not a consideration, some utilities will want to use a lower time dial setting. If this is the case, the time dial setting should be based on the voltage magnitude which can appear across the IAV during high-side ground faults, and the time it takes to clear such faults. If this voltage is not known or cannot be calculated, a reasonable assumption would be that this voltage will be about four times pickup (4 x 5.4 volts). With this multiple of pick-up, select a time dial setting which would provide enough time with margin to ride over clearing of high-side faults.

LOSS OF EXCITATION PROTECTION

Two types of relays are available for this protection. These are:

- CEHS1. This relay has a single mho function which operates with no external time delay.
- CEH52. This relay has two independent mho functions and a built in timer which operates in conjunction with one of the mho units.

The CEH51 would be used on small, less important machines on a power system. Its setting would be as shown in Fig. 5. This setting will detect a loss of excitation from full load down to no load. Normally, no external time delay would be used with this relay. If it is possible, however, for stable swings to enter the relay characteristic (see reference 5), an external time delay of up to 0.5 sets may be added to prevent incorrect tripping.

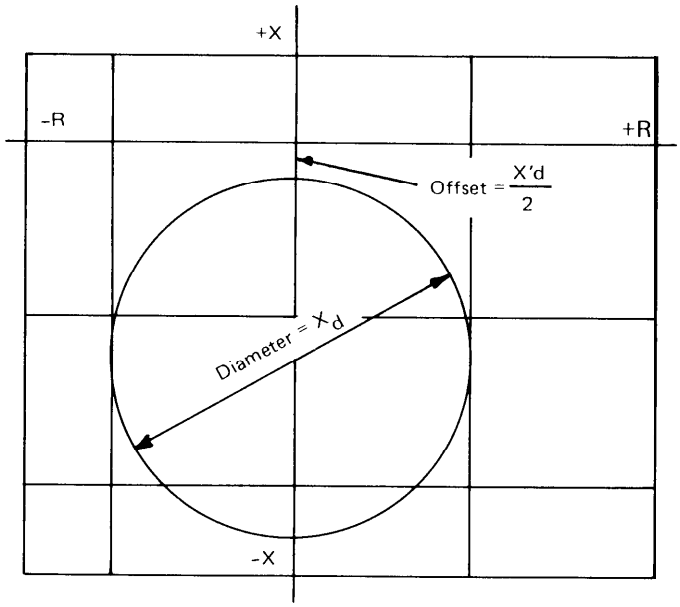


Figure 5. Application of the CEH51.

The CEH52 would be used on the important system generators where optimum protection and security are essential. The settings for this relay are shown in Fig. 6. The unit set with 1.0 per unit impedance on machine base, provides loss of excitation protection from full load down to about 30 percent load. Since a loss of excitation in this loading range has the greatest adverse effects on the generator and system, this unit should be permitted to trip in high-speed.

The second unit, with a diameter setting equal to synchronous reactance Xd, would detect a loss of excitation from full load down to no load. Since it is possible this unit may operate on stable swings, however, a time delay of up to 0.5 sets may be used to prevent incorrect tripping.

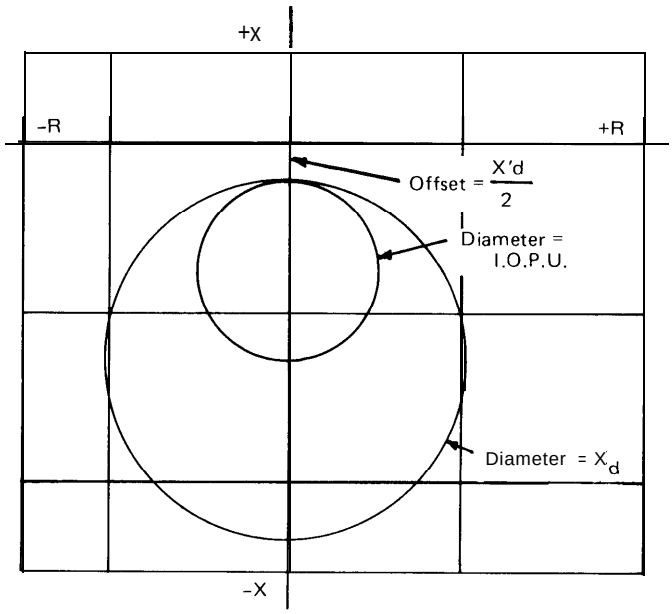


Figure 6. Application of the CEH52.

REVERSE POWER (ANTI-MOTORING) PROTECTION

Reverse power or ant -motoring protection is recommended for all steam turbine generators.

The relay recommended for this function is the GGP53C. This relay has a current pickup level of 10 milliamperes and should be applicable in most cases. The user, however, should obtain the expected no load motoring losses from the steam turbine generator manufacturer to ascertain that there will be sufficient pickup margin.

It is recommended that a 30-second time delay be used with this relay to prevent operation during power swings caused by system disturbances.

It should be noted, this relay has a holding coil which, if not properly adjusted, may cause undesired relay operation. The purpose of this holding coil is to hold the directional unit contacts closed

when the relay is operating near pickup in a location where there is vibration. This holding coil can be adjusted to prevent incorrect operations, or if vibration at the relay location is not severe, the holding coil can be shorted out and eliminated.

UNBALANCED CURRENT (SINGLE PHASING) PROTECTION

The relay recommended for this function for all types and sizes of generators is the SGC1 2, static negative sequence time overcurrent relay. The characteristics of this relay are:

- Tripping Unit
  - A negative sequence current pick-up range of 9 to 20 per cent of generator rated current.
  - A time-current characteristic which exactly matches the generator I_2^2t capability curve. The relay I_2^2t characteristic is adjustable over a range of 2-40.
  - A reset characteristic which approximates generator rotor cooling rates.
  - An optional direct reading meter, calibrated in per cent negative sequence current.
- Alarm Unit
  - Negative sequence current pick-up range: 3 to 20 percent of generator rated current.
  - A three (3) second time delay.

With this sensitivity, the SGC12 is not only capable of providing protection for uncleared unbalanced system faults but it can also provide protection for open conductor faults and/or single phasing of generators.

Of particular concern is the need for open conductor and single phasing protection for generators. There have been a number of recent cases where generator-transformer units were operated with one or two phases open for prolonged periods of time. In most instances, these open phase conditions were caused by the failure of one pole of a high-voltage circuit breaker to close or to open when the generator-transformer unit was connected to or disconnected from the system. Open-phase conditions have also been caused by broken tine conductors or the misoperation of one pole of a line circuit breaker.

With one or two phases open on the high voltage system, the negative sequence current levels in a generator will be a function of generator and system impedances, generator or line loading, and system configuration. While specific values of generator negative sequence currents will vary from system to system, these negative sequence current levels can vary over a range from .05 per unit up to 0.6 per unit of generator rated current. The SGC12 relay, with its sensitive pickup range, can be set to either alarm or to trip for these low levels of negative sequence currents.

It should be noted that the electromechanical negative sequence relay, type INC, with an I_2 tripping level of 0.63 per unit, will not detect an open conductor or single phasing condition in most instances.

OTHER PROTECTIVE CONSIDERATIONS

This section considers supplementary protection and other forms of protection not covered earlier. In addition, it considers equipment and devices used with protective relaying in the generator zone.

TRIPPING MODES

Figures 1 and 2 show three methods of tripping with the electrical protection in the generator zone: tripping hand-reset lockout relay 86G; tripping self reset auxiliary relays 94G1 and 94G2.

Tripping via the lockout relay 86G trips the main and field breakers, the turbine, and the boiler. This mode is used where generator and/or transformer faults are involved and for backup operations.

Relay 94G1 initiates tripping of the main generator breaker(s) and the field breaker(s). This mode is used where it may be possible to quickly correct the abnormality and therefore would permit reconnecting the machine to the system in a short period of time.

In both of the above instances, it will be necessary to transfer the station auxiliaries to the standby source.

Relay 94G2 only initiates tripping of the main generator breaker(s). This mode is used where, during some system disturbances, it is desirable to keep the station auxiliaries connected to the generator. For example, during a loss of synchronism or a disturbance which produces low frequency tripping, the standby source may be out of phase with the generator or non-existent. This tripping mode would permit reconnecting the machine to the system with a minimum of delay.

These are the only tripping modes for electrical protection discussed in this guide.

For other turbine protective functions, a so-called sequential tripping mode is used. In this mode, the turbine valves are tripped first, then auxiliary contacts on these valves are used to initiate tripping of the main and field breakers. With this approach, backup protection for possible failures in the valve auxiliary contacts, the control circuitry, and/or the breakers is provided by the reverse power relay. To provide this backup function, the reverse power relay (32) must be connected to initiate tripping of the main and field breakers through 94G1 as shown in Figures 1 and 2.

Another tripping mode used is a simultaneous trip. In this approach, the protective relays used to trip the turbine valves would also initiate a simultaneous trip of the generator main and field breakers. In some instances, a time delay is used in the breaker tripping chain. If such time delay is used, the effect of this time delay on the generator and/or system should be determined.

GENERATOR BACK-UP PROTECTION

Phase Fault Backup

Backup protection against relay failure is not normally applied to unit generator transformers. Their operation is closely supervised, and the protection listed under 2A1 provides enough overlap and duplication of the various protective functions to make separate backup relaying considered to be unnecessary. It should be noted that the system phase fault backup relays, type CEB or IJCV, provide some measure of backup protection for both the generator and the main transformer.

Ground Fault Backup

Generator ground backup protection may be provided in several ways.

1. One approach is to use a simple time overcurrent relay 51GN connected to CTS in either the neutral of the primary winding of the distribution transformer or in the distribution transformer secondary as shown in Fig. 1. With either method, the CT ratio and relay pickup setting are selected with the intent of providing the same degree of protection as with the overvoltage relay IAV51K. In general, it is difficult to achieve this sensitivity, since the relay must be set so that it will not pick up on the zero sequence harmonic currents and the normal 60 Hz unbalance currents that flow in the neutral. The time setting for this relay must be coordinated with the IAV51K and the potential transformer fuses.

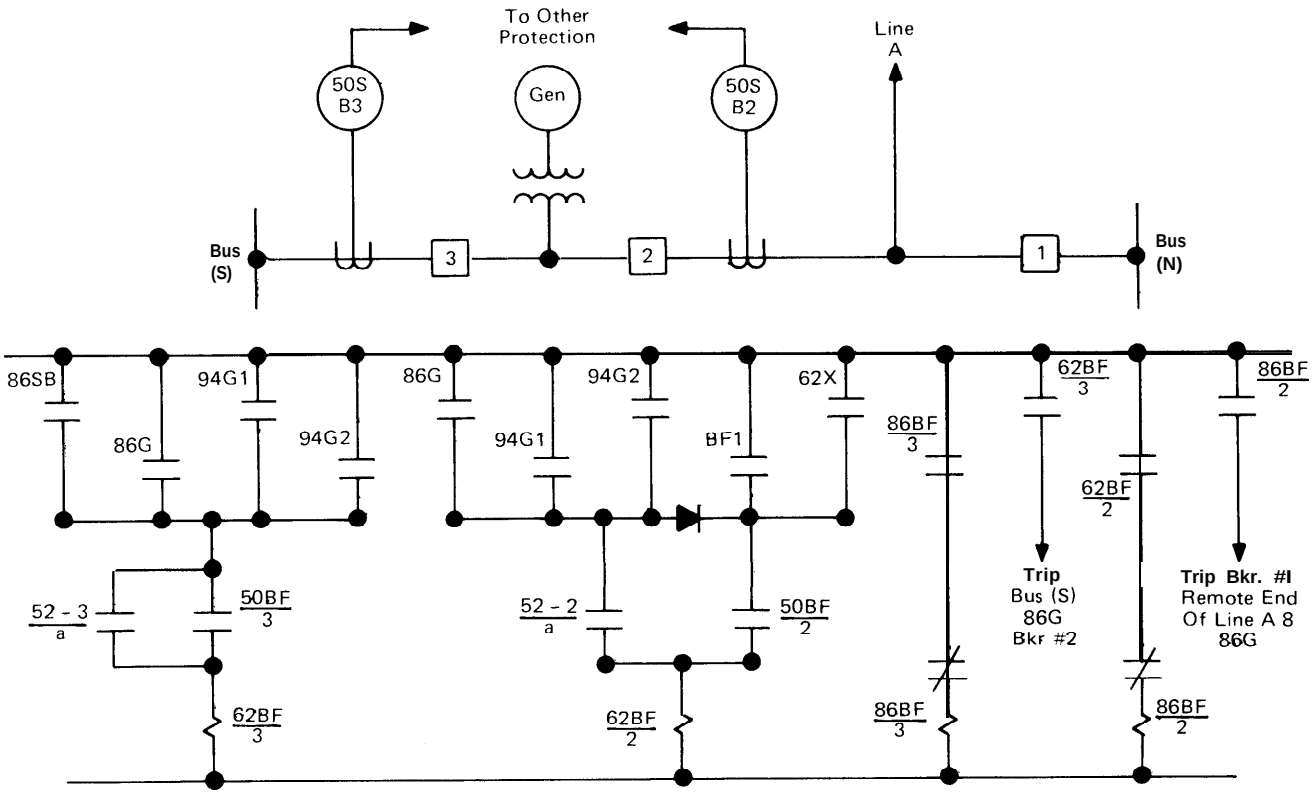
2. Another approach is to use potential transformers connected grounded wye-broken delta at the machine terminals with an IAV51K connected across the broken delta. This method provides the same degree of protection as with the overvoltage relay across the generator neutral resistor. It should be noted that this approach acts as a high impedance grounding bank and therefore its effect on generator grounding and fault current levels should be determined.

3. Some utilities use a voltmeter connected across the grounding resistor to check the integrity of the grounding system and the availability of the ground protection. Under normal conditions, zero sequence harmonic voltages (mostly 3rd harmonic) will be present across the resistor. The absence of these harmonic voltages would be an indication of possible problems with the grounding system and/or relays.

Breaker Failure Relaying

It is recommended that breaker failure relaying be incorporated as an integral part of the overall protection for all types of generators.

Protection for failure of the H.V. main generator breaker(s) can be accomplished through the use of electromechanical or static current detectors and timers as in the breaker failure schemes for line



Device	Type	Function
*50BF	CHC	Fault Detector
*62BF	SAM11	Timer
62X	NGA1 5A	Bkr Failure Initiate E/M Line Relays
86BF	HEA61	Lockout Relay
86G	HEA61	Gen. Zone Prot. Lockout Relay
86SB	HEA61	Bus (S) Lockout Relay
94G1,94G2	HGA14 or HFA53	Gen. Zone Prot. Trip Relays
BFI		Bkr Failure Initiate Static Line Relays

"As an alternate use SBC21 static breaker failure relay.

Figure 7.

protection. A simplified breaker failure arrangement is shown in Figure 7. Since two main breakers are involved, there is a current detector and timer associated with each breaker.

Operation of the scheme is simple and straightforward, Like all such schemes, when the primary and backup protection detect an internal fault, they will attempt to trip the necessary breakers and at the same time start the breaker failure timers. If a breaker does not clear the fault in a specified time, the timer wilt trip other breakers necessary to clear the fault. In this case, if breaker No. 3 fails, bus (S) must be tripped; if breaker No. 2 fails, breaker No. 1 and the remote end of line (A) must be tripped. Since the remote relays on line (A) will not be able to detect a low level fault in the generator-transformer zone, some form of transferred tripping will have to be used.

The only thing unusual about the arrangement in Figure 7 is the use of breaker auxiliary "a" contacts in the circuit. These breaker auxiliary contacts are necessary for controlling the backup timer

in case the current level is below pickup of the fault detector relays (50B R/2, 50B F/3) as could be possible for a low-level transformer fault, a motoring condition, or low level unbalanced currents. If independent pole control is used, breaker "a" contacts from each pole (three required) would have to be placed in parallel with the current detector 50BF contacts for each breaker. It should be noted auxiliary switches on circuit breakers are not otherwise used in breaker failure relaying because (1) the auxiliary switch or mechanism may have been the cause of the breaker failing to clear the fault or (2) the breaker may have opened mechanically without clearing the fault. In this case, the breaker "a" switches must be trusted for low-level faults.

It should be emphasized that the intent of the simplified scheme shown in Fig. 7 is to illustrate only the general approach used for achieving breaker failure backup. The user should design and implement the scheme to obtain the required level of reliability. For example, Figures 1, 2, and 7 show a single lockout relay 86G. It would be desirable to split the generator zone protection into groups and have each group operate a separate lockout relay. For instance, separate the primary and backup relays and have each operate a separate lockout relay. In this way, a single lockout relay failure will not eliminate all protection.

Another factor to consider is the operating procedure when a machine is shut down for maintenance. When a ring bus, or a breaker and a half, or a double breaker-double bus arrangement is used on the high side, it is common practice for some utilities to isolate the unit generator and close the high-voltage breakers to close the ring or tie the two busses together. Under these conditions, it will be necessary to isolate the lockout and trip relay contacts to prevent unnecessary breaker failure backup operation during relay testing. Some utilities use knife switches for this function. Whatever approach is used, the protection provided for accidentally energizing a generator on turning gear should never be removed from service when the machine is shut down for maintenance.

GENERATOR ENERGIZED ACCIDENTALLY ON TURNING GEAR

When a generator is energized three phase while on turning gear, it will behave and accelerate as an induction motor. The equivalent machine impedance during the high slip interval can be represented by negative sequence reactance (X2) in series with negative sequence resistance (R2). (Note: Negative sequence reactance of a steam turbine generator equals subtransient reactance X"dv.) The machine terminal voltage and current during this interval will be a function of generator, transformer and system impedances. If the generator-transformer is connected to an infinite system the machine currents will be high (several per unit) and conversely if the unit is connected to a weak system, the machine current could be low (1-2 p.u.).

During the period the machine is accelerating, high currents will be induced in the rotor and the time to damage may be on the order of a few seconds. To prevent damage to the rotor, stator, bearings, etc., it is desirable that high-speed protection be provided for this contingency.

There are several relays used in the generator zone that may detect or can be set to detect this condition. These are:

- Loss of excitation relay, CEH.
- Reverse power relay, GGP, ICW.
- System backup relays CEB, IJCV.

CEH Relay

With normal settings, subtransient reactance (X"dv) may be just inside at the top of the relay characteristic (see reference 1). Depending on the offset used and the relay and impedance tolerances, CEH operation may be marginal in some instances. Therefore, each application should be checked. In any event, it is not recommended that the offset be reduced to obtain more margin since the CEH may then operate incorrectly on stable swings.

It should be noted, the CEH is usually taken out of service by breaker "a" switches when the machine is shut down. When the breaker is closed, the ''a'' switch may fail to close and place the relay back in service and therefore there may be a question as to the dependability of the CEH for this protection.

Reverse Power Relays (GGP, ICW)

The power into the machine during this contingency can be approximated by using machine current and the negative sequence resistance R_2. It would appear, the resulting power levels will be in the pickup range (3 percent or higher of machine rating) of the GGP and the ICW. If the terminal voltage is low during this contingency, however, the GGP may not produce an output.

The GGP relay has an ac voltage timer (IAV) whose pickup level is about 48 percent of rated volts. If the terminal voltage is below this level, as it may well be, the relay will never time out.

Both types of relays involve time delay and therefore are less desirable.

System Backup Relays (CEB13C, IJCV)

In many instances, the CEB relay can be adjusted to provide protection. The relay would have to be connected at the machine terminals and the reverse offset adjusted to encompass subtransient reactance. In general, a 4 ohm offset would be required. This relay has time delay associated with it which would be undesirable in this instance.

The IJCV should be able to detect this condition with normal settings. Its pickup, however, should be checked with the expected terminal conditions. This relay has an advantage in that it can operate as a simple overcurrent relay in case the potential supply is disconnected when the machine is down for maintenance. Again, the time delay associated with this relay would be undesirable.

It should be noted that if the potential supply is disconnected during maintenance, the GGP, the ICW, and the CEH will become inoperative. The CEB, with its offset setting, will have a voltage proportional to current which may produce sufficient torque to cause relay operation.

Speed Relay

Gas turbines have an auxiliary relay in the Speedtronic Governor which will continually attempt to trip the unit during underspeed conditions.

Supplementary Protection

While there are several generator zone relays which may provide protection for this contingency, the performance of this protection may be marginal and requires close checking. Therefore, the preferred approach is to provide supplementary protection designed for this specific purpose.

Figure 8 shows a protective scheme which has been suggested for this contingency. This approach uses a frequency relay-current relay combination which would only be in service when the machine is shut down.

The current relay could be a sensitively set instantaneous relay of the type CHC12. It should have a continuous rating which would permit it to be picked up continuously when the machine is on-line and carrying full load. The pickup setting of this relay should be 50 percent or less of the minimum generator current seen during this contingency.

The frequency relay would be an IJF51C2A, with a pickup setting range of 48-55 Hz. This relay would be set well below any emergency operating frequency.

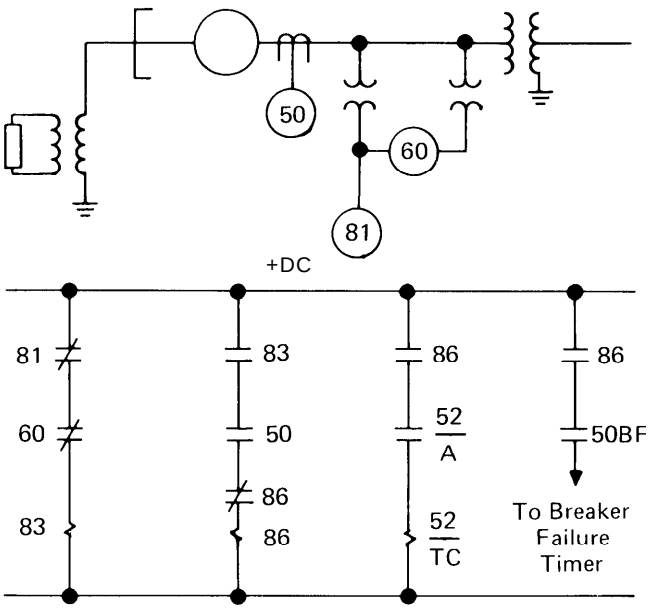
The voltage balance relay CFVB prevents incorrect operations for an IJF loss of potential under normal operating conditions.

When the generator is shut down and the frequency drops below the IJF setting, the IJF resets and energizes auxiliary relay 83 which in turn arms the current relay circuit. If the generator is accidentally energized, the time delay dropout of 83 permits 50 to pick up and trip the unit in high speed.

Whichever scheme is used to provide protection for accidentally energizing a generator on turning gear, the protection should be connected to trip the main breaker, initiate breaker failure backup, and be so implemented that it is never taken out of service when the machine is shut down for maintenance.

START-UP OR SHUTDOWN PROTECTION

During start-up or shutdown of a generator, the unit may be operated at reduced and/or decreasing



50 -- Instantaneous Overcurrent Relay, Type CHC12
50BF – Breaker Failure Current Detector
60 – Voltage Balance Relay, Type CFVB
81 – Frequency Relay, Type IJF51C2A
(Depending on the aux. relay used (83), it may be necessary to bypass seal-in circuit. The HGA17A specified for 83 will not pick up this seal-in).
83 – Auxiliary Relay Time Drop Out, HGAI7A, (15 cycle drop out time.)
86 – Lock Out Relay – HEA

Figure 8. Supplementary protection for accidentally energizing a generator on turning gear.

frequency with field applied for a period of time. When operating frequency decreases below rated, the sensitivity of most generator zone protective relays will be adversely affected. The sensitivity of a few relays will only be slightly reduced while other relays will not provide adequate protection or become inoperative. Reference 13 and Fig. 9 show the effects of frequency on the pickup of relays which may be used in the generator zone. It should be noted that the transformer differential relay (BDD and STD) and generator ground relay (IAV51 K) both being tuned relays, lose sensitivity rather rapidly below 60 Hz. The generator differential CFD is less affected by frequency but becomes insensitive below 30 Hz. Induction-disk, current-type relays could provide adequate protection down to 20 Hz, while plunger-type relays are not adversely affected by off-frequency operation.

In general, current transformer performance will not be a problem at reduced frequency (Reference 13). While CT voltage output decreases with frequency, the reactive component of most relay burdens also decreases with frequency. Therefore, the reduction in CT capability is compensated for by a reduction in relay burden.

Supplementary protection for a unit generator transformer during the start-up or shutdown period can be provided through the use of plunger-type relays as shown in Figure 10. Supplementary ground fault protection can be provided by using a PJV voltage relay connected in parallel with the IAV51 K.

Supplementary phase fault protection can be provided by using PJC overcurrent relays in either one of two methods:

1. Placing PJC relays in series with the operate circuits of the transformer differential relay.

2. Place PJC relays in the CT phase leads which connect to the generator backup relays or metering.

Method (I), the preferred approach, is capable of providing sensitive supplementary protection. The PJC relay would be set above the difference current that will flow in the differential circuit during normal 60 Hz operation. This is to prevent operating the PJC relay continuously energized. In general, the difference current will be small and it will be possible in most instances to set the PJC at its minimum 2 amp pickup.

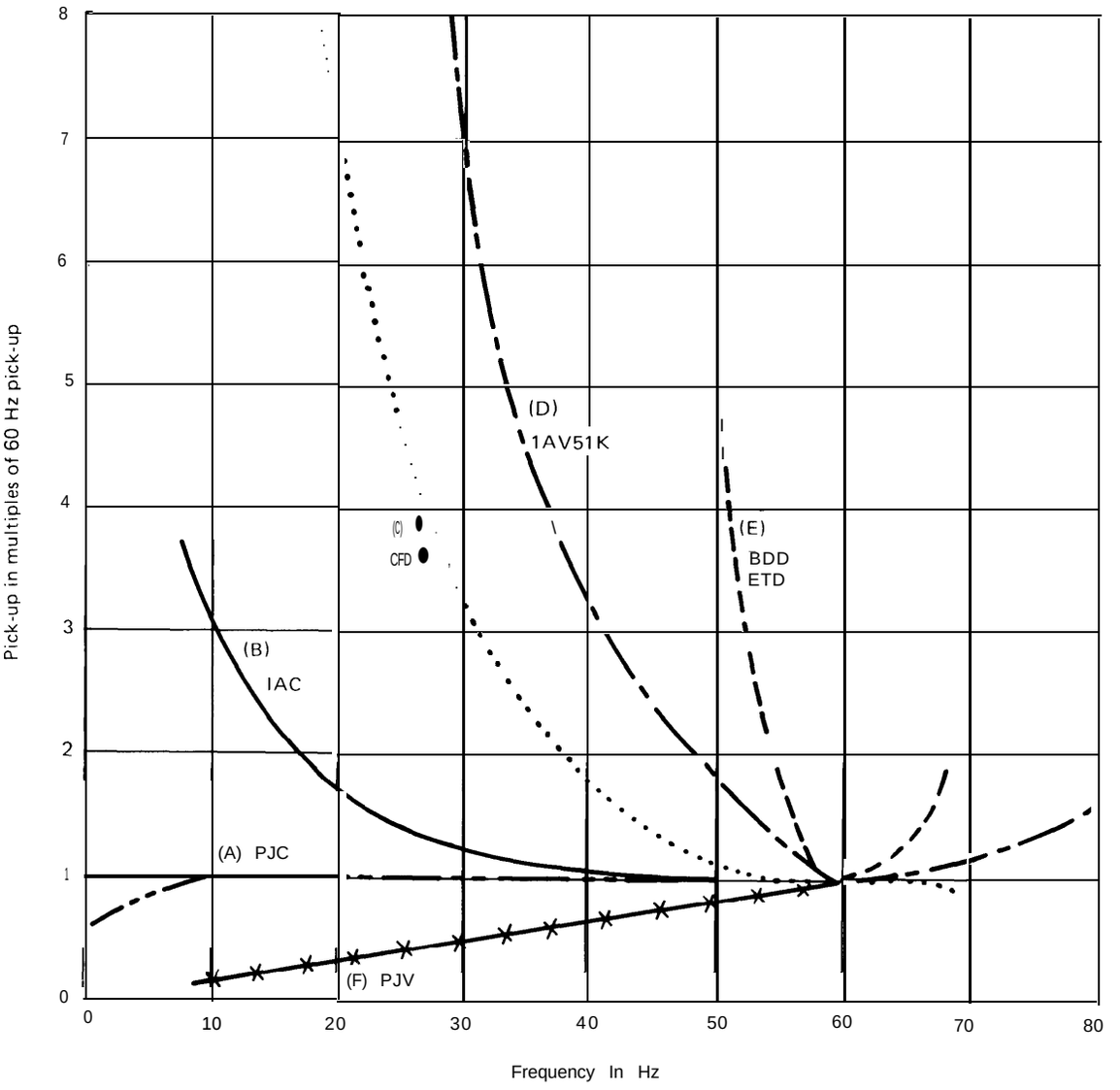
One factor which must be considered when using this method is the effect of the PJC burden on the 60 Hz operation of the transformer differential relay. The PJC current coil will be in the differential circuit at all times and will present additional burden to the CTS. The effect of added burden on the low voltage CTS will generally be negligible but it may be necessary to check the ratio error of the high voltage CTS.

When method (2) is used, the PJC would have to be set above maximum full load current so that the relay would not be picked up continuously when the machine is on line. This setting would not provide sensitive protection during start-up or shutdown. If a pickup setting below full load current

is used, the PJC coil would have to be short circuited before the machine is connected to the system since plunger relays cannot be operated picked up continuously.In general, short circuiting current coils is not considered a desirable practice. Method (2) has an advantage in that it may also be used to provide protection for accidentally energizing a generator on turning gear. In this instance, it could be used in place of the CHC as discussed earlier.

When a generator is bussed at low vottage (see Fig. 2), supplemental ground protection could be provided by using a sensitive PJC current relay in series with the time overcurrent relay normally used for protection. Supplemental phase fault protection could be provided by method (2). In this case, it would be necessary to short circuit both the phase and ground PJC current coils when the machine is connected to the system if both relays could be picked up continuously.

The supplementary protection for both types of generator arrangements is usually inactivated when the units are connected to the system. This can be accomplished by opening the trip circuits with a breaker“b” switch or with an underfrequency relay as shown in Fig. 10.



(A) — - - — Plunger Type Current Relay

(B) ——— Induction Overcurrent Relay

(C) • • • • • • • • Generator Differential Relay

(D) — - — Generator Ground Relay

(E) - - - - Harmonic, Restraint Transformer Differential Relay

(F) —X—X— Plunger Type Voltage Relay

Figure 9. Relay pick-up vs. frequency.

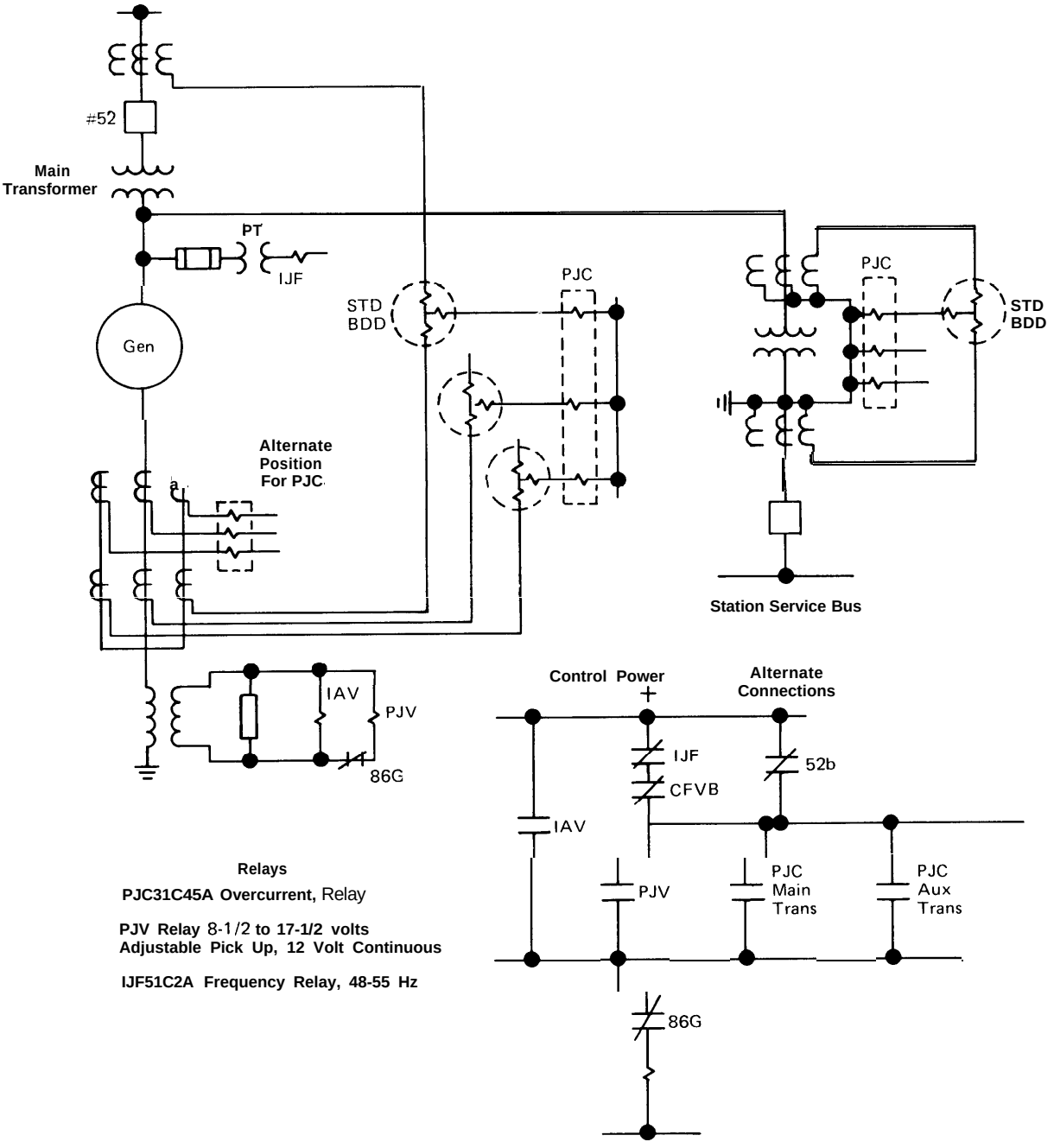


Figure 10. Protection during low frequency operation.

CURRENT TRANSFORMERS

Current transformers having small air gaps in the core are available on large steam turbine generators. The purpose of these air gaps in the CT cores is to reduce residual magnetism to a point where it will not have any adverse effect on the transient performance of the CTS (see Reference 8). Basically these CTS provide added security against incorrect differential relay operation for both internal and external faults. Where this added security isdesired, air gap CTS would be used for the generator differential protection and for the generator CTS used in the overall (transformer) differential scheme.

In addition, LSTG CTs rated 15,000 primary amperes and higher are provided with shield windings. The purpose of these windings is to shield the core from extraneous flux fields (proximity effects) which might cause localized saturation in the core and thereby cause excessive CT error during a fault condition.

POTENTIAL TRANSFORMERS

For many years, it has been and still is recommended that line-to-line rated PTs connected line-to-ground be used on high resistance grounded generators. This practice minimizes the possibility of ferro-non-linear resonance when the generator and transformer are connected as a unit.

It should be noted it is possible to have a PT ferro-resonance problem with the unit generator-transformer arrangement if the generator is disconnected and the PTs are left connected to the delta winding of the GSU transformer, which is then used to serve station auxiliary load. With the PTs connected to an ungrounded system, the possibility of ferro-non-linear resonance is almost a certainty. To suppress ferro-resonance for this operating condition, resistance loading should be applied across each phase of the secondary winding. Resistance loading equal to PT thermal rating may be required.

If the detection of ground faults is desired during this mode of operation, this can be accomplished in one of two methods:

1. Connect an overvoltage-undervoltage relay, Type IAV53M, across one phase of the secondary winding.

2. Connect a secondary winding in broken delta and use an IAV51 K across the broken delta.

With both methods, it will be necessary to check the effects of the loading resistance on the relay voltages during a ground fault.

To avoid coordination problems, it may be necessary to remove this supplementary protection when the unit is operated in normal mode. In addition, the resistance loading applied to suppress ferro-resonance should be removed when the generator is reconnected.

SUB-SYNCHRONOUS RESONANCE

When a generator is connected to a system that has series capacitor compensation, it is possible to develop sub-synchronous frequency oscillations and shaft torques which can be damaging to the generator. Therefore, when a generator will be operating on a series-compensated system, it is recommended that a protective system be provided to control the sub-synchronous resonance duty on the generator. This complex subject and the protection recommendations are discussed in Reference 14.